

B physics at DØ

“The Tevatron Connection”

Fermilab, USA

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Representing the DØ collaboration



B physics at hadron colliders

■ Pros

- Large production cross section
- All b species produced
 - B^\pm , B^0 , B_s , B_c , Λ_b , Ξ_b

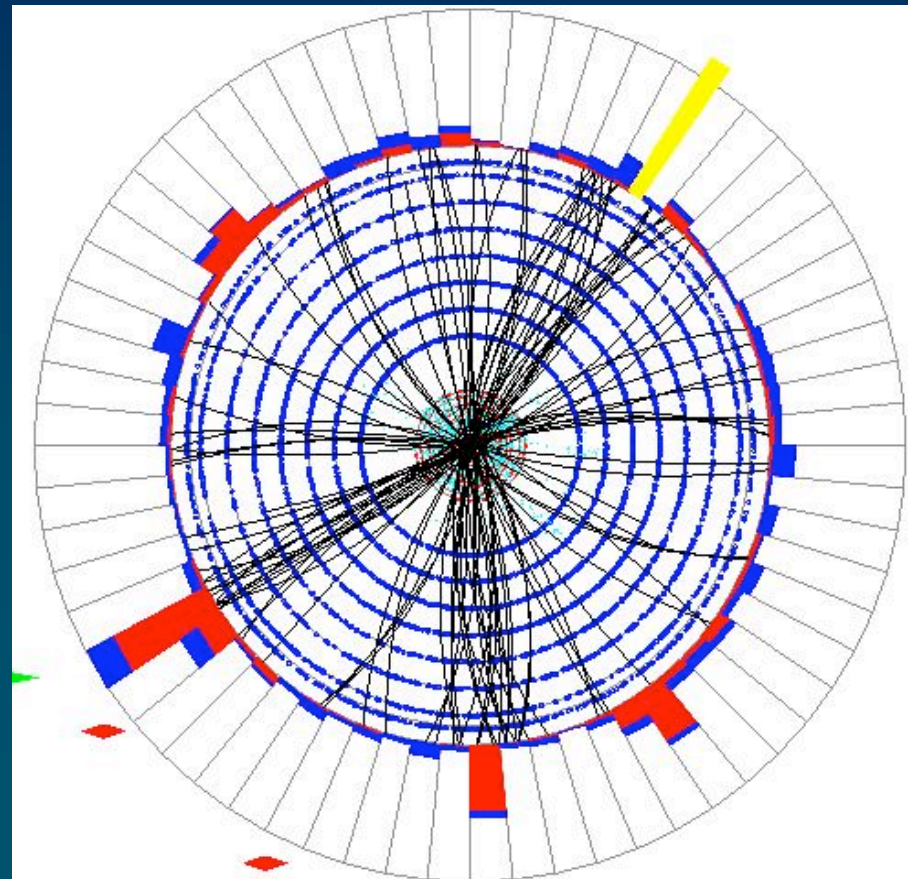
✓ Cons

- Inelastic cross section is a factor of 10^3 larger with roughly the same pT spectrum
- Many decays of interest have BR's of the order 10^{-6}
- Large combinatorics and messy events

$$\sigma(p\bar{p} \rightarrow b\bar{b}) \approx 150 \text{ nb} \quad \text{at 2 TeV}$$

$$\sigma(e^+e^- \rightarrow b\bar{b}) \approx 7 \text{ nb} \quad \text{at } Z^0$$

$$\sigma(e^+e^- \rightarrow B\bar{B}) \approx 1 \text{ nb} \quad \text{at } \Upsilon(4S)$$



B Physics at DØ

■ QCD studies

- b-quark cross sections and correlations
- Quarkonium cross sections and polarization
- Spectroscopy: baryons, X particle, B^{**}

■ B hadron lifetimes

- Especially B_s - $\Delta\Gamma/\Gamma$, B_c , Λ_b

✓ Rare decays

- $B_s \rightarrow \mu^+ \mu^-$

✓ CP Violation

✓ B_s mixing

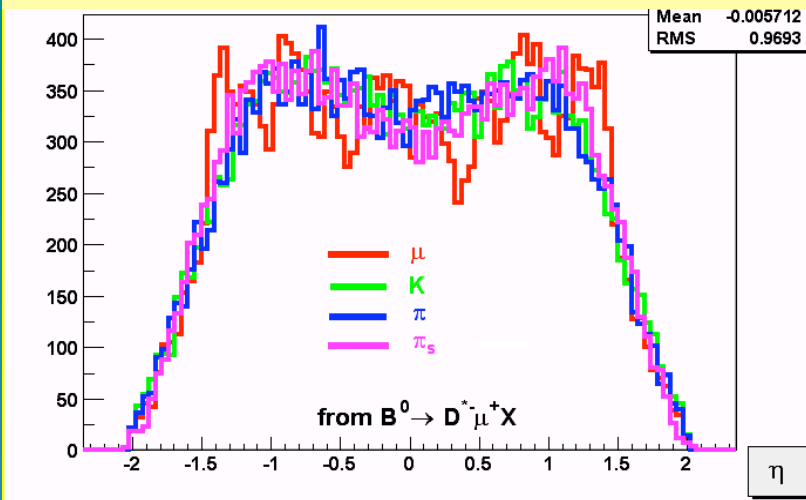
The DØ Run II detector

- The DØ detector has undergone extensive upgrades:
 - Silicon vertex detector
 - $|\eta| < 3.0$
 - Central fiber tracker and pre-shower detectors
 - 2 T solenoid magnet
 - Low pT central muon trigger scintillators
 - New forward μ system
 - L2 silicon track trigger commissioning now



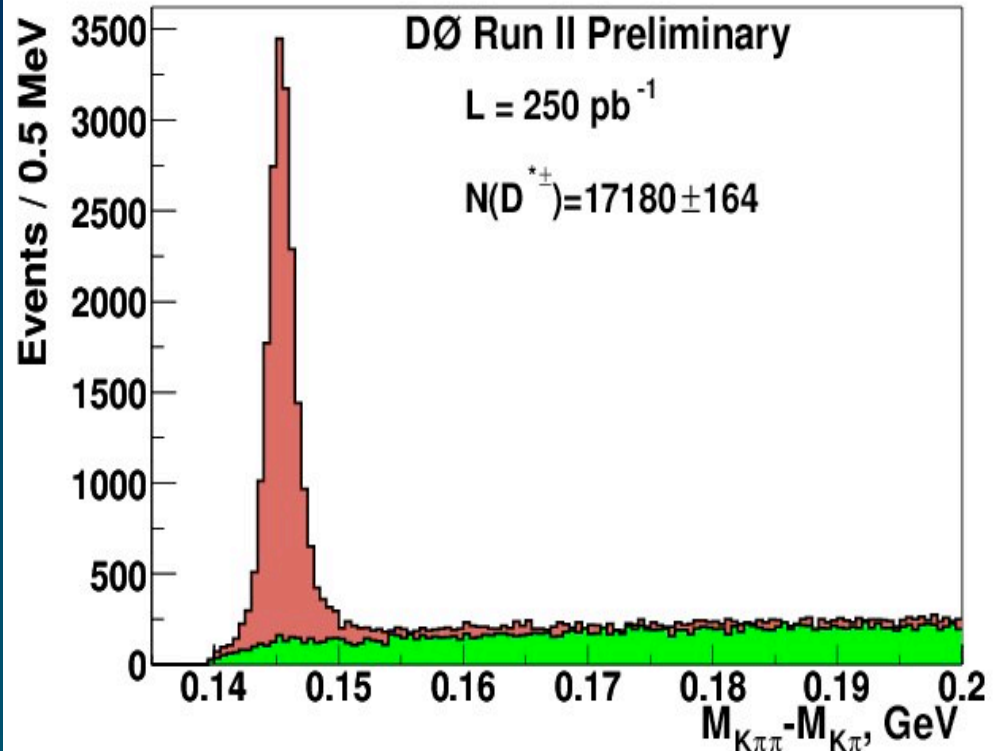
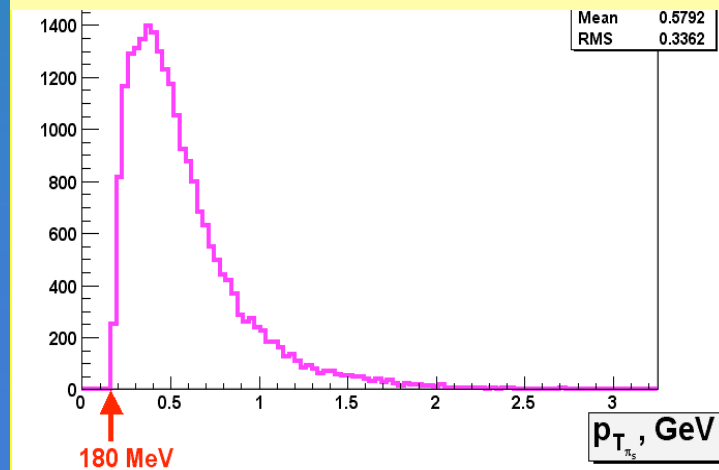
DØ extended tracking coverage

η of all B decay particles



Data from semileptonic decays ($B \rightarrow \mu D^* X$)

p_T of soft pion from $D^* \rightarrow D^0 \pi$

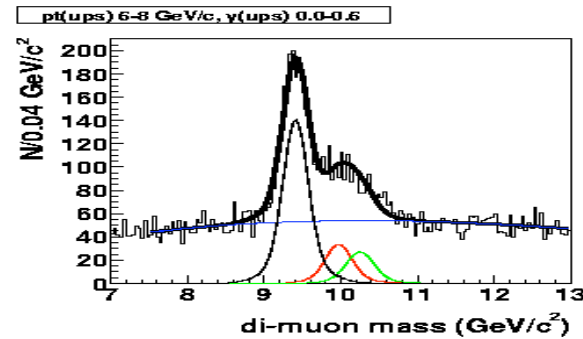
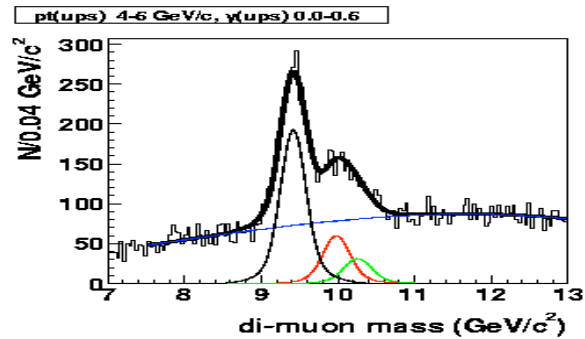


Quarkonium production

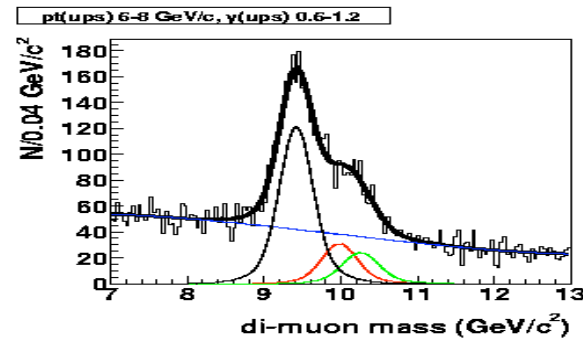
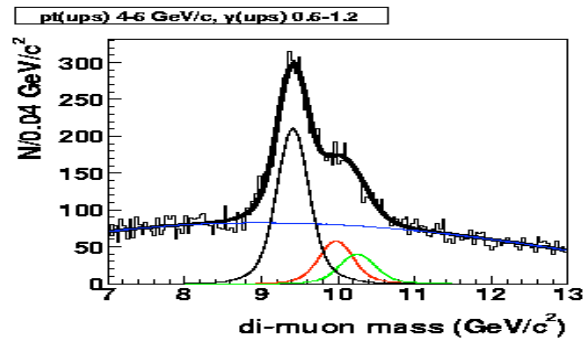
■ Motivation

- Run I direct charmonium and upsilon cross sections were orders of magnitude larger than the theoretical predictions at the time
- Color octet model attempts to describe data but relies on experimental/phenomenological inputs
 - Needs measurements from many different experimental conditions to check consistency
 - Polarization predictions are on shaky ground
 - Low p_T upsilon cross section (CDF) not described well by model

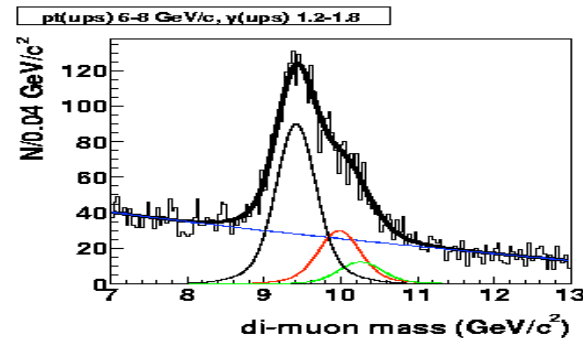
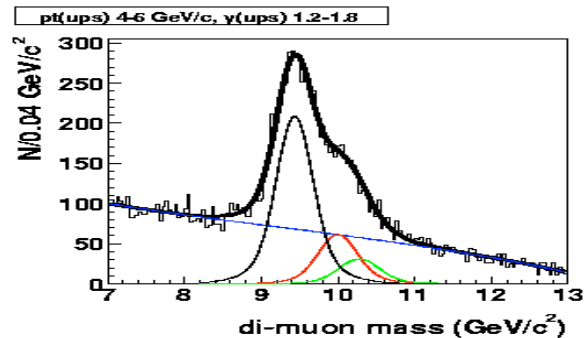
Upsilon signals



$$0.0 < |y^\Upsilon| < 0.6$$



$$0.6 < |y^\Upsilon| < 1.2$$

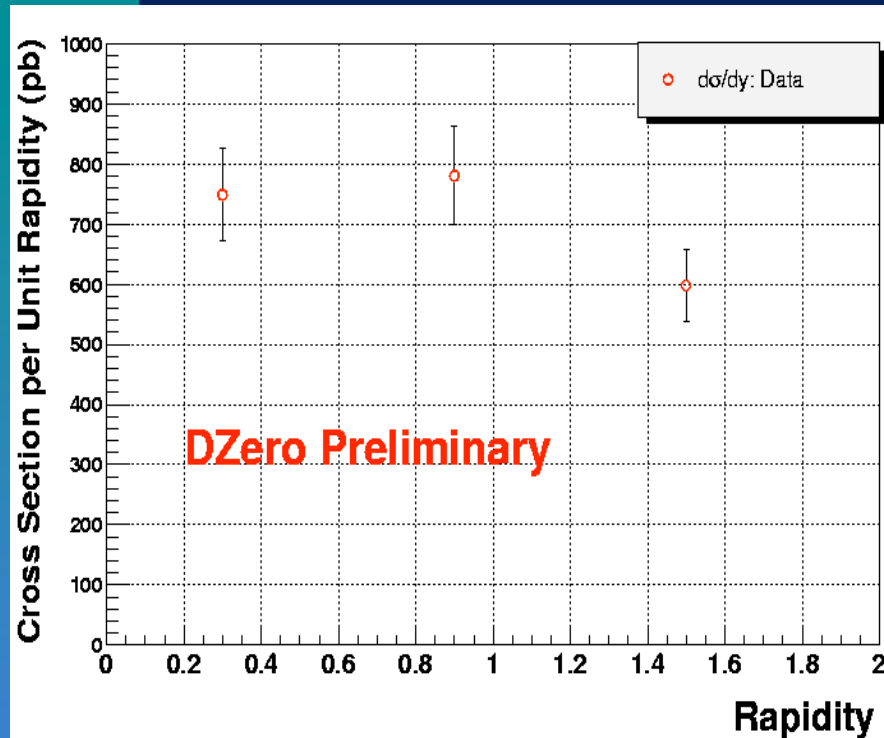


$$1.2 < |y^\Upsilon| < 1.8$$

p_T^Υ 4-6 GeV

p_T^Υ 6-8 GeV

$\Upsilon(1S)$ Cross Section



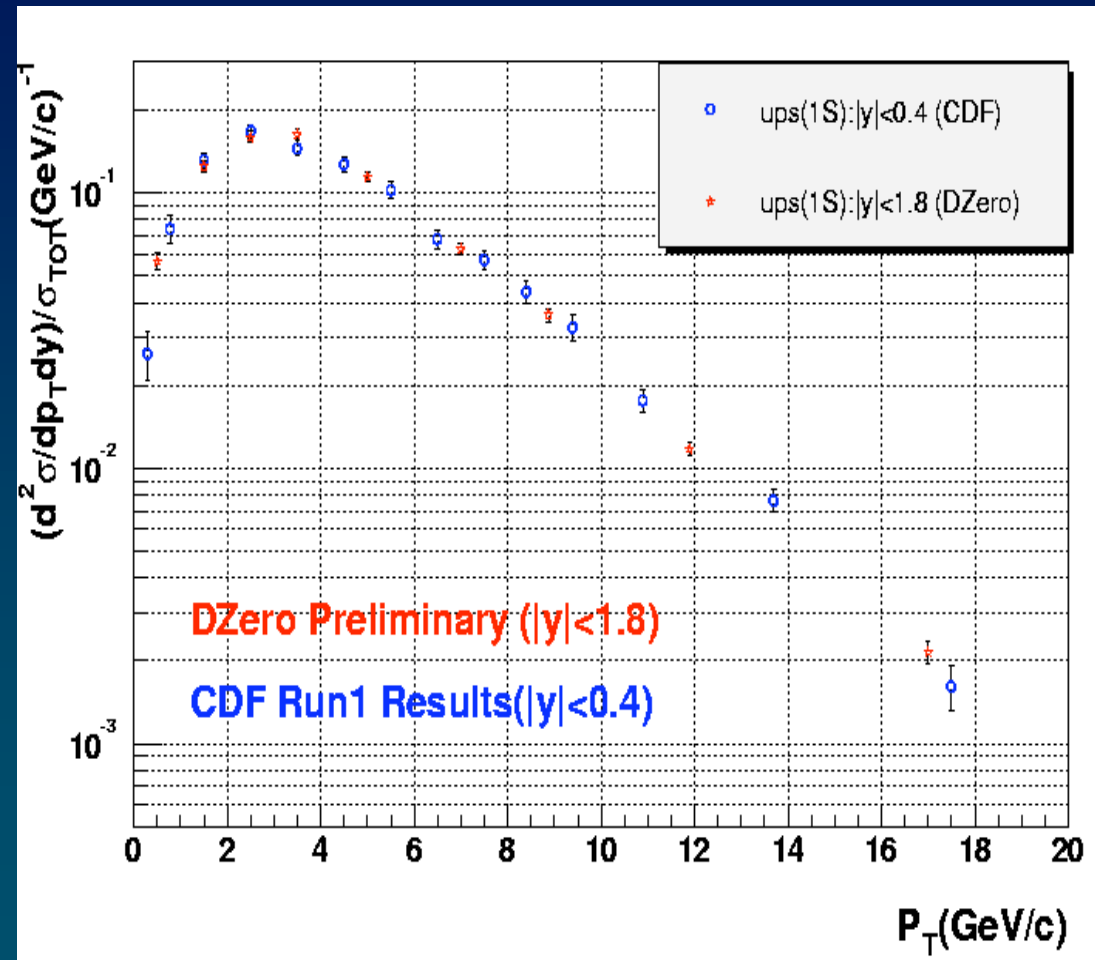
$ y^\Upsilon $	# of $\Upsilon(1S)$	Cross section × BR (pb, per unit of y)
0.0-0.6	13,040	$749 \pm 20 \pm 75$
0.6-1.2	16,867	$781 \pm 21 \pm 78$
1.2-1.8	18,122	$598 \pm 19 \pm 56$
0.0-1.8	46,331	$695 \pm 12 \pm 65$

CDF RunI ($|y| < 0.4$) : $680 \pm 15(\text{stat}) \pm 18(\text{sys}) \pm 27(\text{Lum})$ pb

Expect $\sim 11\%$ increase for $\sqrt{s} = 1.8 \text{ GeV} \rightarrow 1.96 \text{ GeV}$

$\Upsilon(1S)$ Cross Section

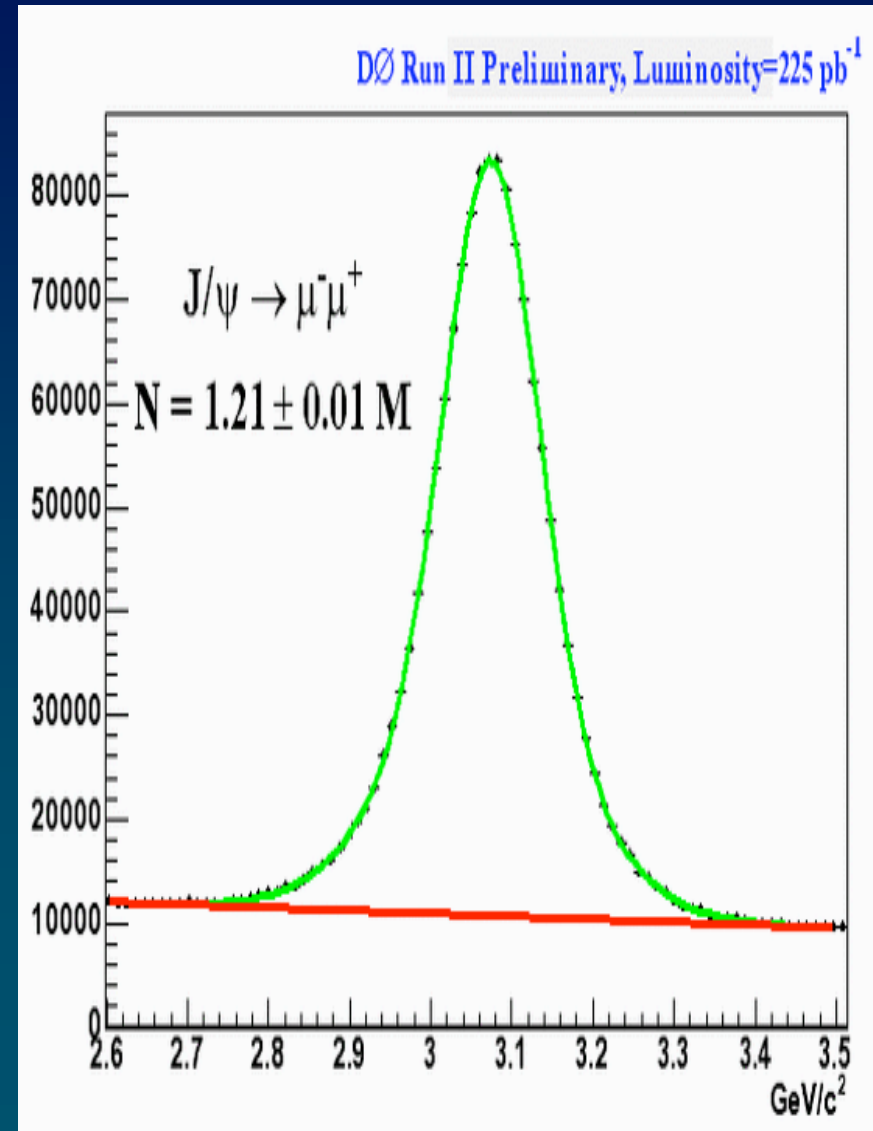
- DØ and CDF measurements agree
- New calculation by Berger et al now describes low pT data



Polarization measurement is in the works

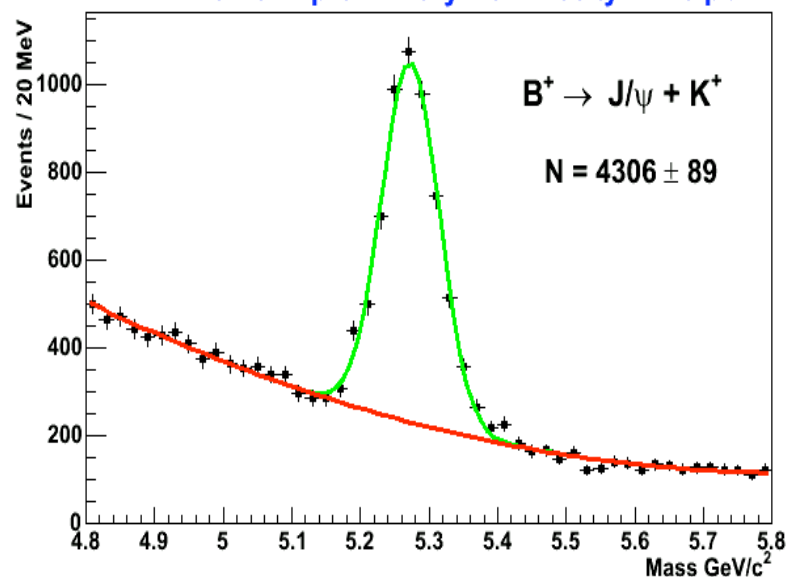
$J/\psi \rightarrow \mu^+ \mu^-$ our bread and butter

- Easy to trigger on
- Good source of exclusive and interesting B decays
- Interesting in its own right
 - X-section and polarization provide good test of color octet model
- 1.2 M J/ψ 's in 225 pb^{-1} of good data taken up to Feb 2004

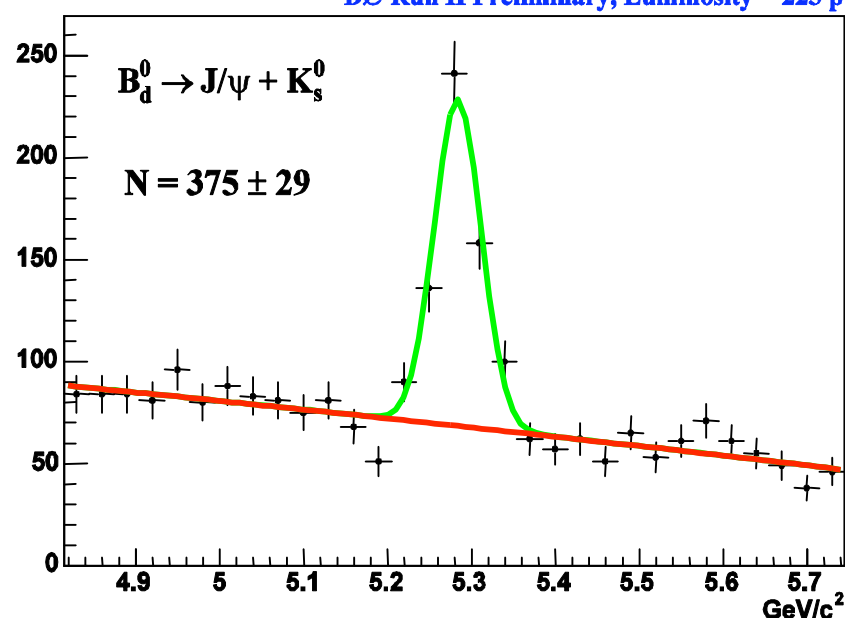


Fully reconstructed B's

D0 RunII preliminary. Luminosity $\sim 225 \text{ pb}^{-1}$



DØ Run II Preliminary, Luminosity = 225 pb^{-1}



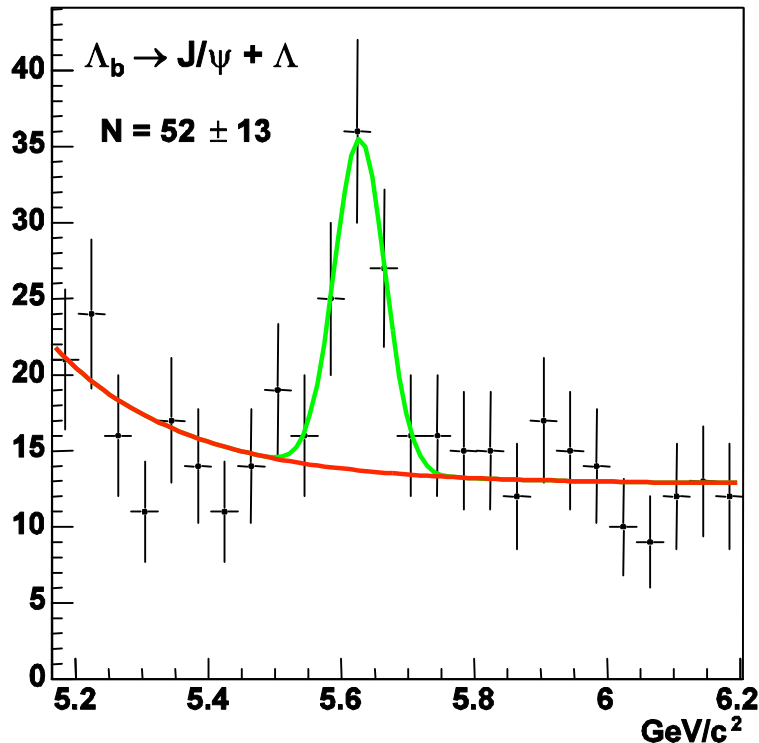
■ QCD studies

- Better for cross section measurement – no missing decay product extrapolation uncertainties, also very nice for correlations – hadron vs. other lepton or jet, or even other hadron!

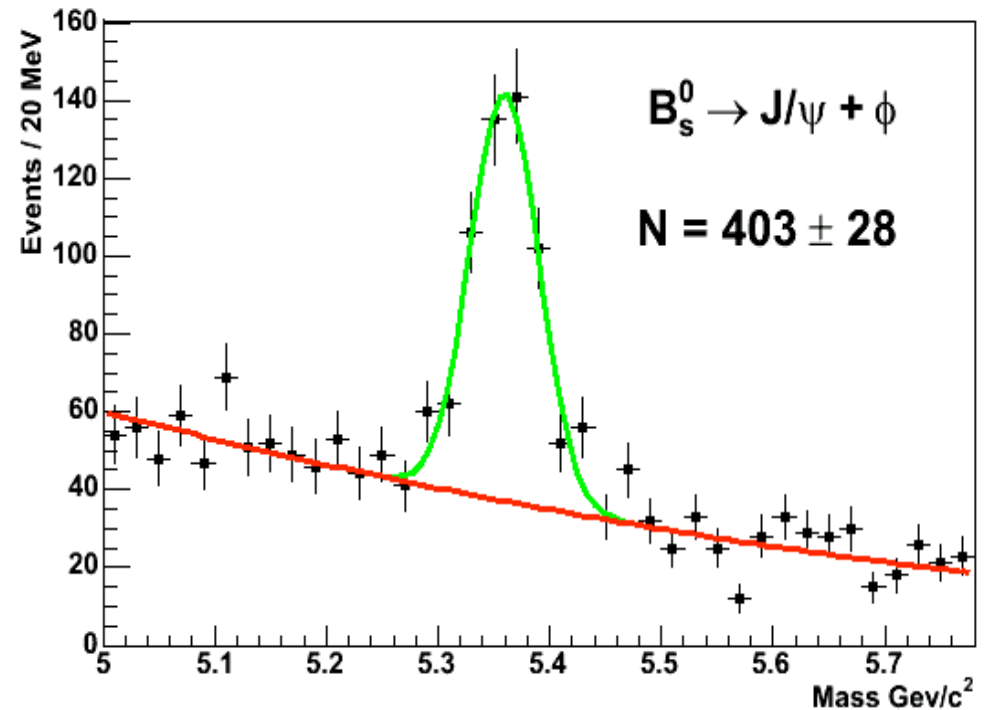
■ CP violation, lifetime measurements, B^{**} spectroscopy

More fully reconstructed B's

DØ Run II Preliminary, Luminosity = 225 pb⁻¹



D0 RunII preliminary. Luminosity ~ 225 pb⁻¹

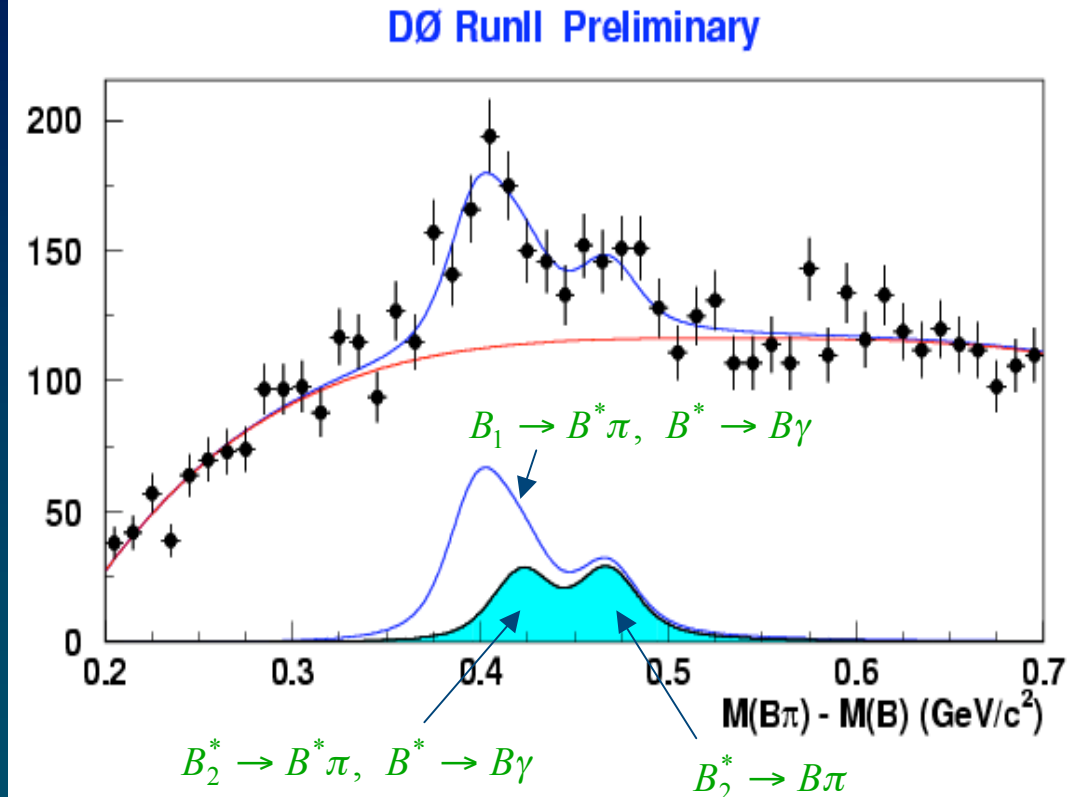


- These states are not accessible at B-factories
 - Lifetimes of considerable interest
 - CP violation in B_s, very small in SM – look for new physics

B spectroscopy – B**

First observation of separated states

- For hadrons with one heavy quark, QCD has additional symmetries (Heavy Quark Symmetry)
- The spin of the heavy quark decouples and meson properties are given by the light quark and gluon degrees of freedom



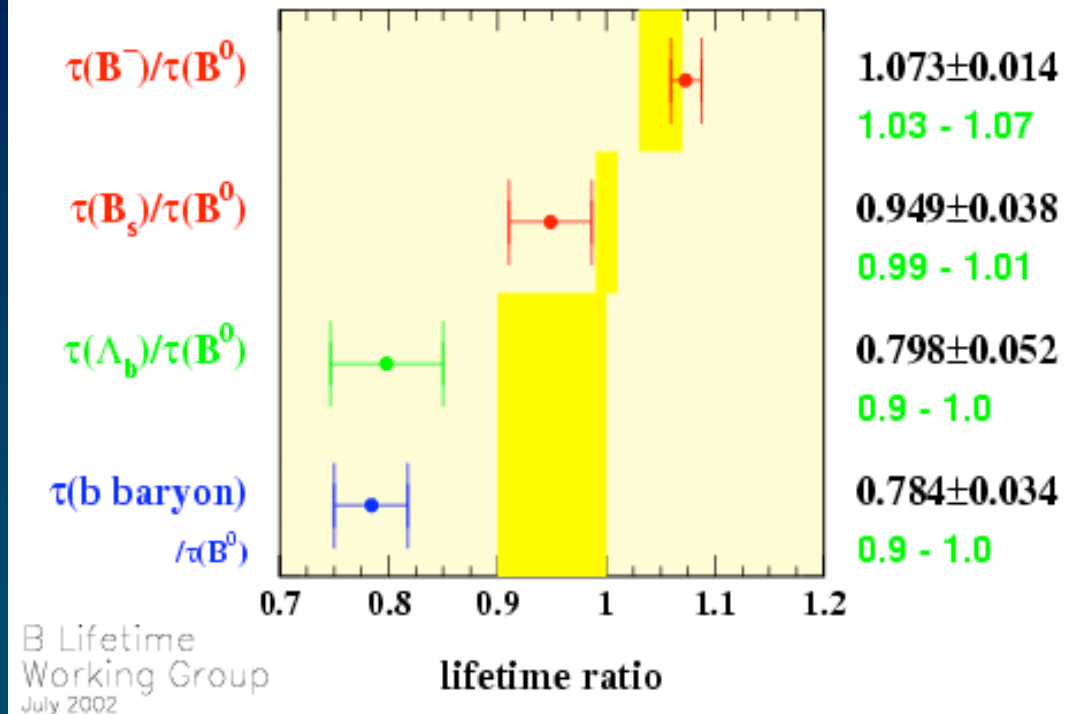
$$M(B_1) = 5724 \pm 4(stat) \pm 7(syst) \text{ MeV} / c^2$$

$$M(B_2^*) - M(B_1) = 23.6 \pm 7.7(stat) \pm 3.9(syst) \text{ MeV} / c^2$$

B lifetimes

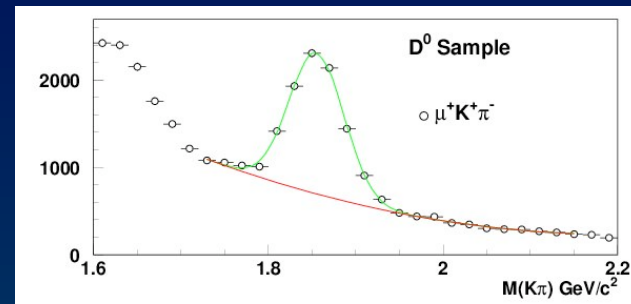
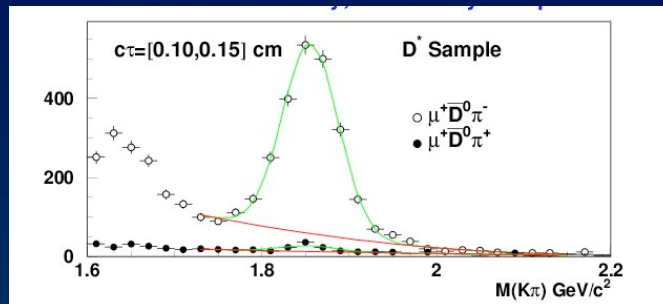
■ Good tests of theory

- Operator product expansion (OPE)
- Heavy quark effective theory (HQET)
- Lattice gauge predictions



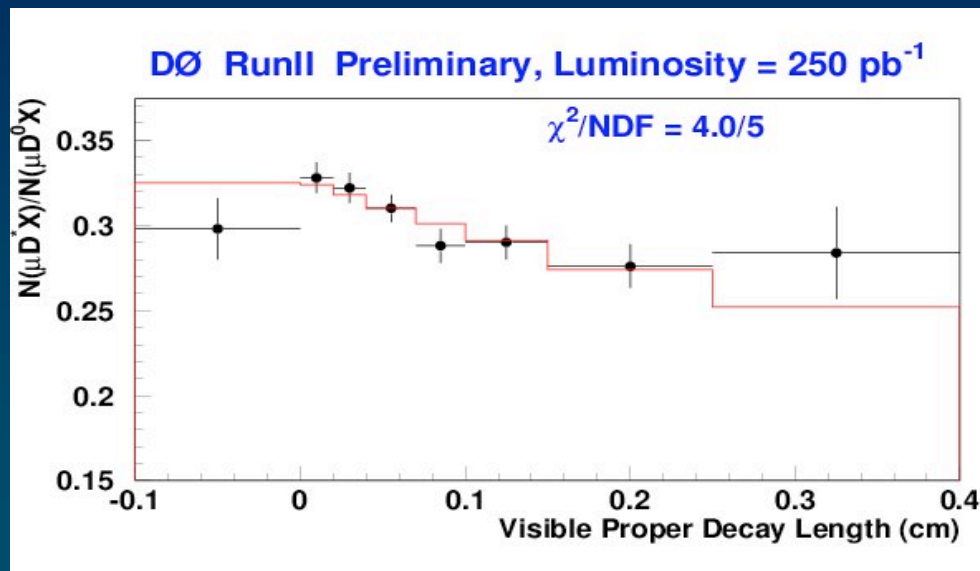
Is there a problem with the Λ_b lifetime?

$\tau(B^+)/\tau(B^0)$



Novel technique using large semileptonic B samples

- take ratio of D mass peaks in 8 pseudo time bins
- Many systematic error cancel

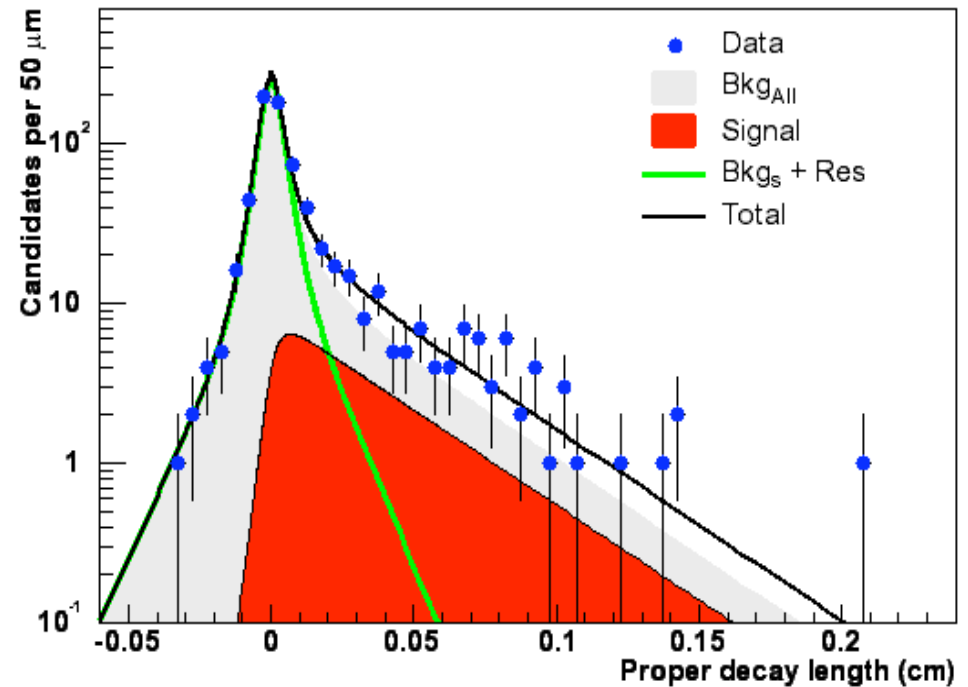
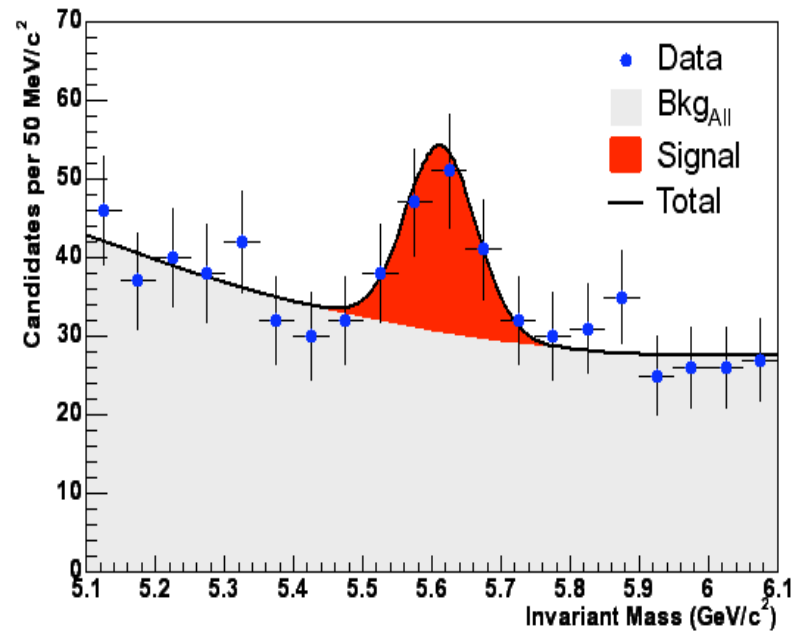


$$\tau(B^+)/\tau(B^0) = 1.093 \pm 0.021 \text{ (stat)} \pm 0.022 \text{ (syst)}$$

One of the worlds most precise measurements

Λ_b lifetime

$$\bar{E}_b \rightarrow J/\psi + \bar{E}$$



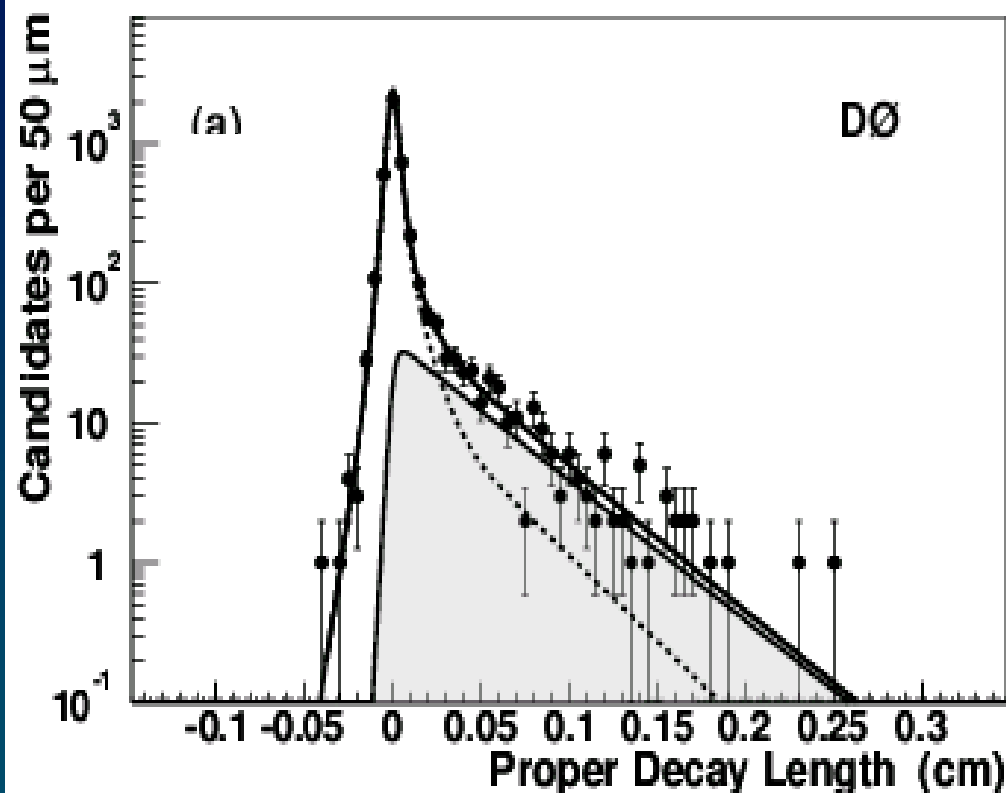
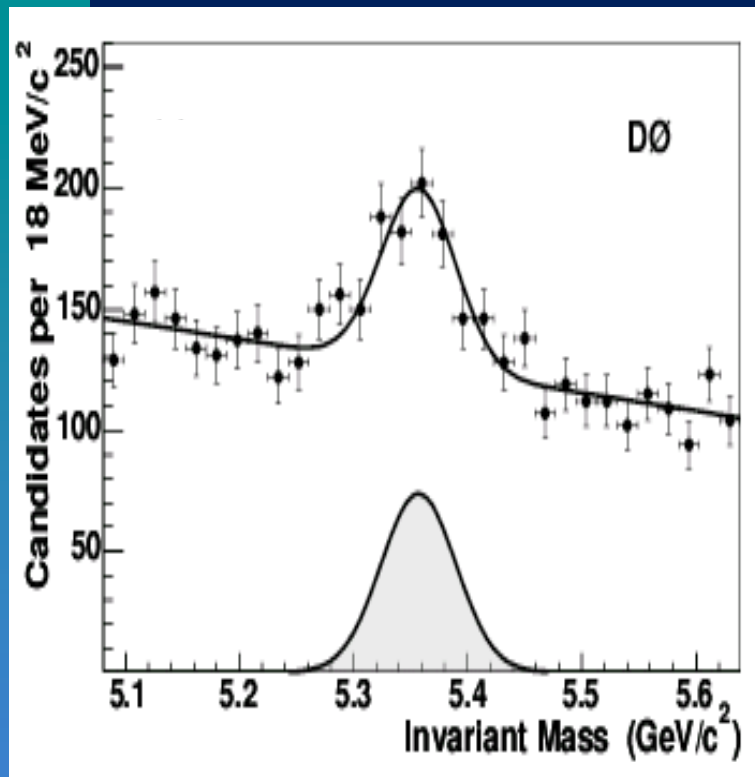
- 2D mass – decay length fits: 61 ± 12 signal events

$$\tau(\Lambda_b) = 1.22 \pm 0.22 \pm 0.04 \text{ ps}$$
$$\tau(\Lambda_b) / \tau(B^0) = 0.87 \pm 0.17 \pm 0.03$$

Consistent with world average – and with theory

B_s lifetime

$$B_s \rightarrow J/\psi + \phi$$



- 2D mass – decay length fits: 337 ± 25 signal events

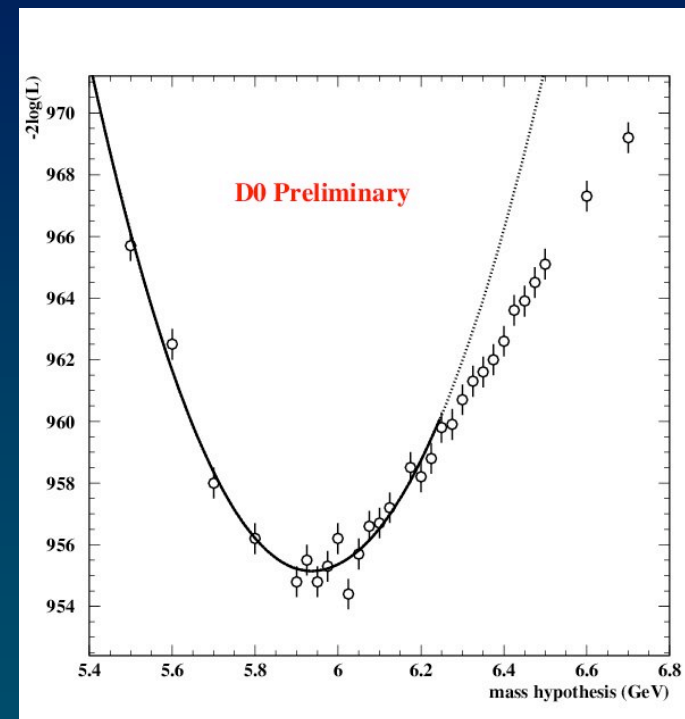
$$\tau(B_s) = 1.44 \pm 0.10 \pm 0.02 \text{ ps}$$

$\Delta\Gamma_s$ measurement in progress

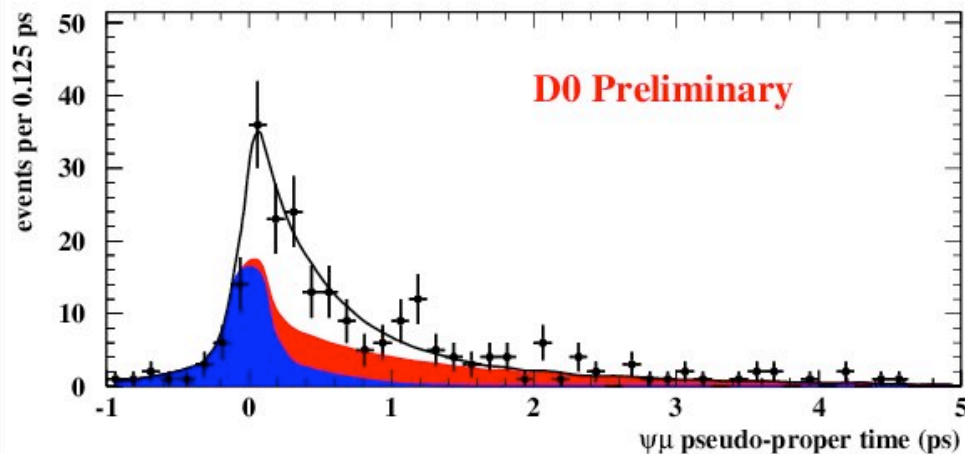
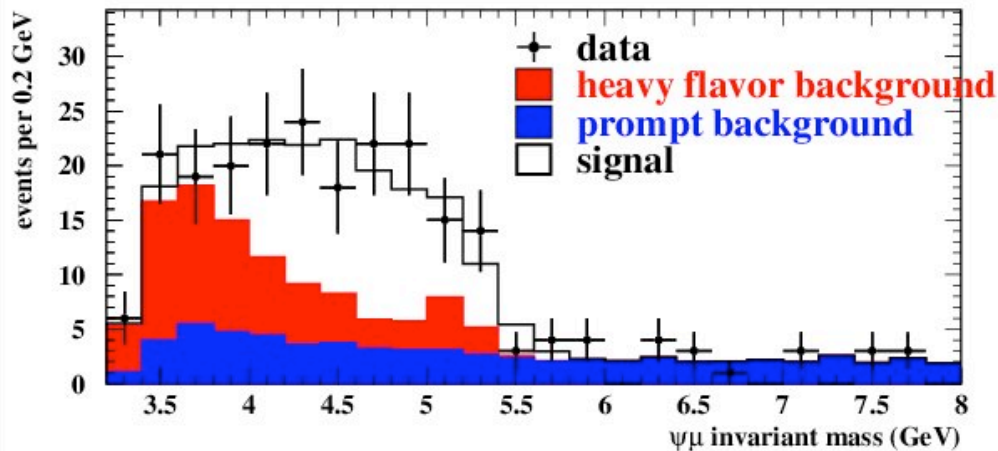
Observation of B_c

■ $B_c \rightarrow J/\psi + \mu + X$ selection

- $J/\psi \rightarrow \mu^+ \mu^-$ selection
- associate tracks with the mass constrained J/ψ vertex
- pick lowest χ^2 J/ψ + track combination
- If track is a medium or tight muon that passes through inner and outer muon layers, it is a B_c candidate – if not, background control event
- 231 B_c candidates, 59k background
- prompt background determined from $c\tau < 0$ ps events
- heavy flavor background determined from $c\tau > 2$ ps events
- combined lifetime and mass LL fits with various mass hypotheses



B_c mass and lifetime



$$N(B_c) = 95 \pm 12 \pm 11$$

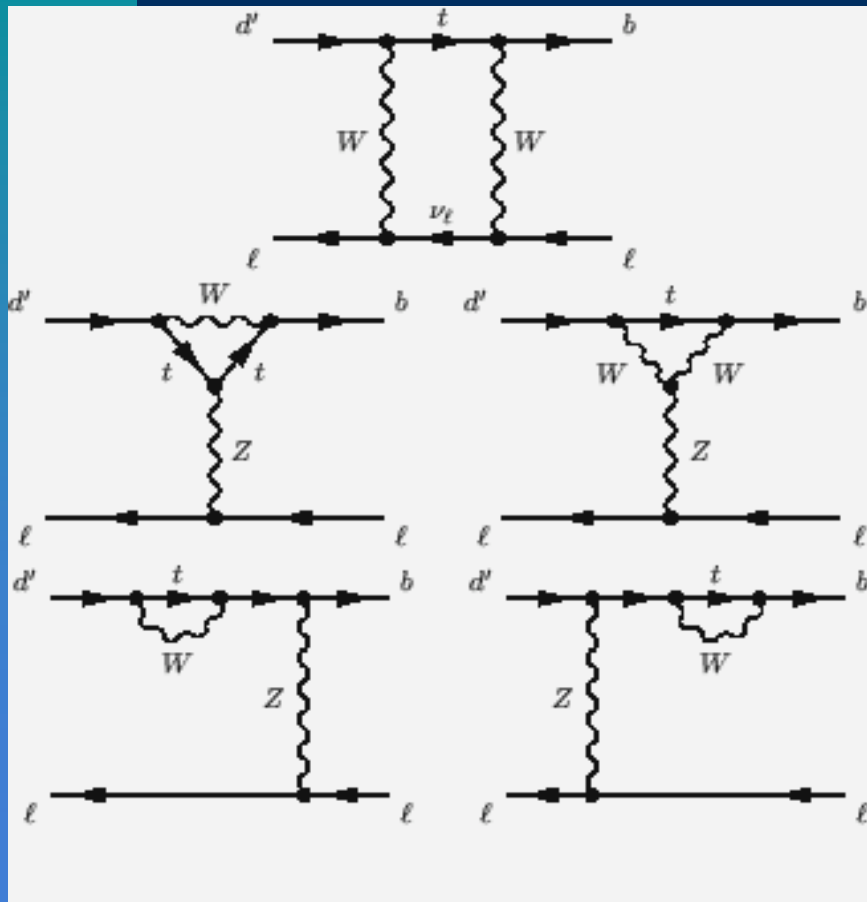
$$M(B_c) = 5.95 \pm 0.14 \pm 0.34 \text{ GeV}/c^2$$

$$\tau(B_c) = 0.45 \pm 0.12 \pm 0.12 \text{ ps}$$

$$B_s \rightarrow \mu^+ \mu^-$$

Standard Model predictions

$$BR(B_s \rightarrow \mu^+ \mu^-) = (3.4 \pm 0.5) \cdot 10^{-9}$$

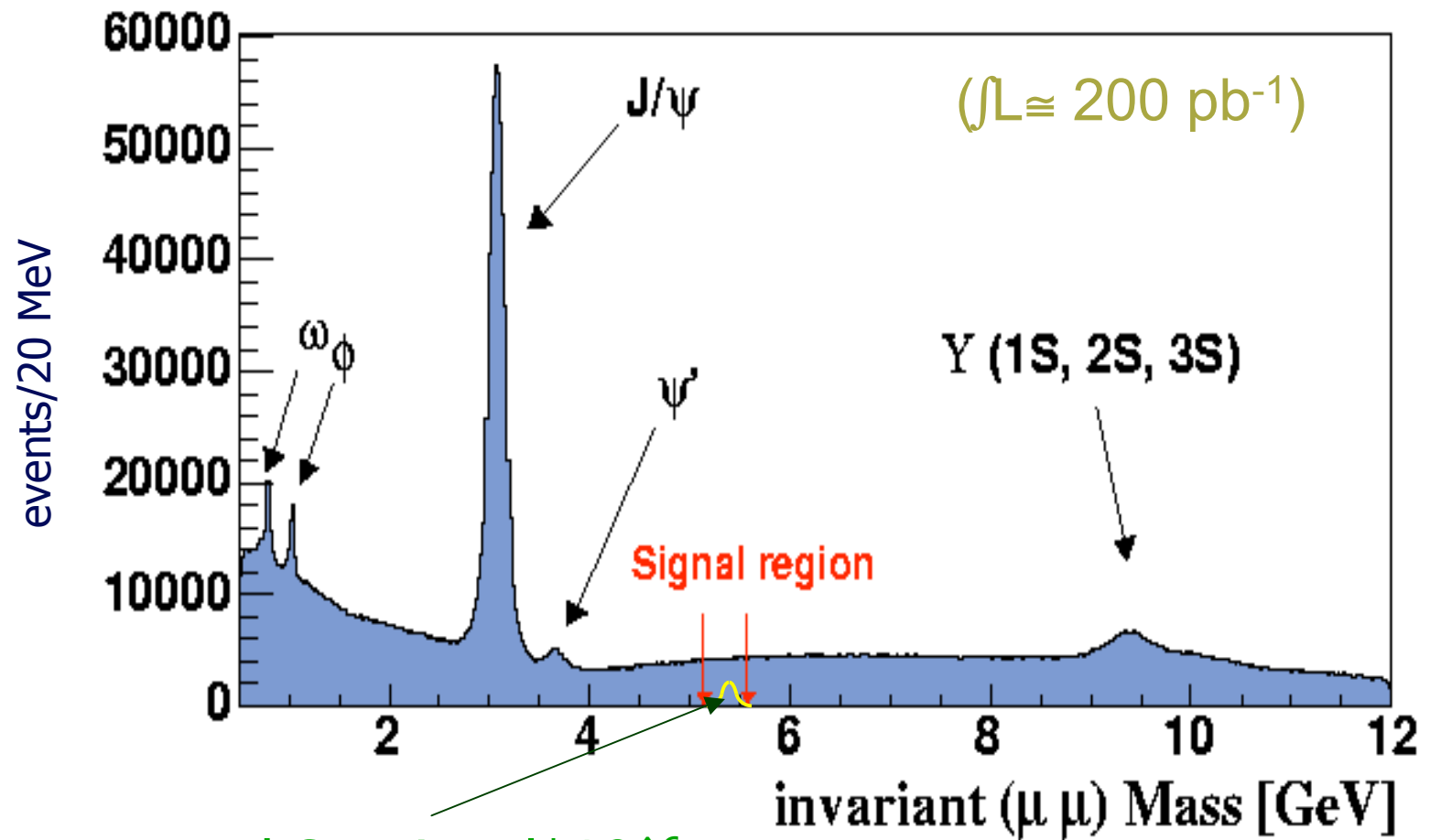


Experimental (CDF) limit 95% CL

$$BR(B_s \rightarrow \mu^+ \mu^-) < 7.5 \cdot 10^{-7}$$

Excellent place to look for
SUSY and other new physics

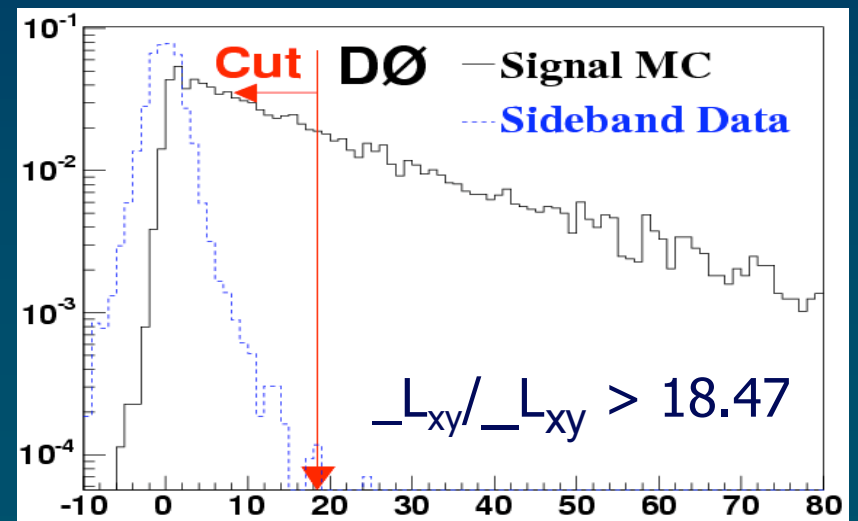
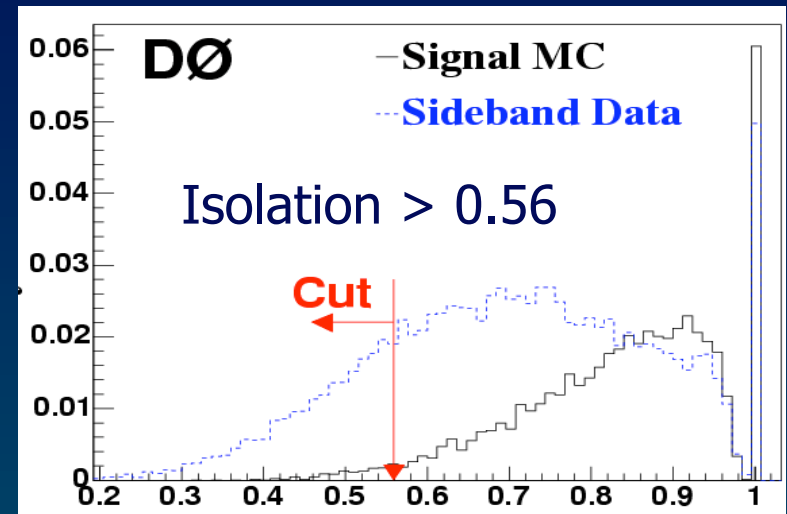
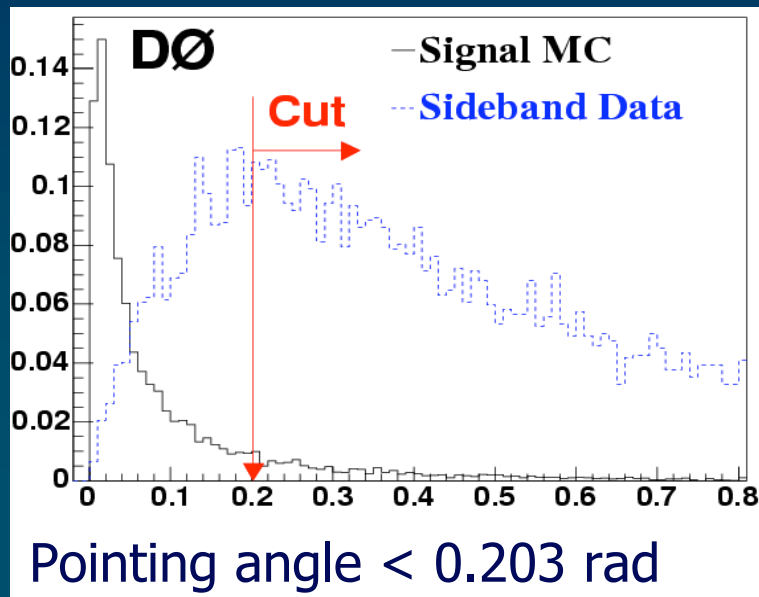
Dimuon mass spectrum



Expected SM signal $\times 10^6$

Optimization of cuts

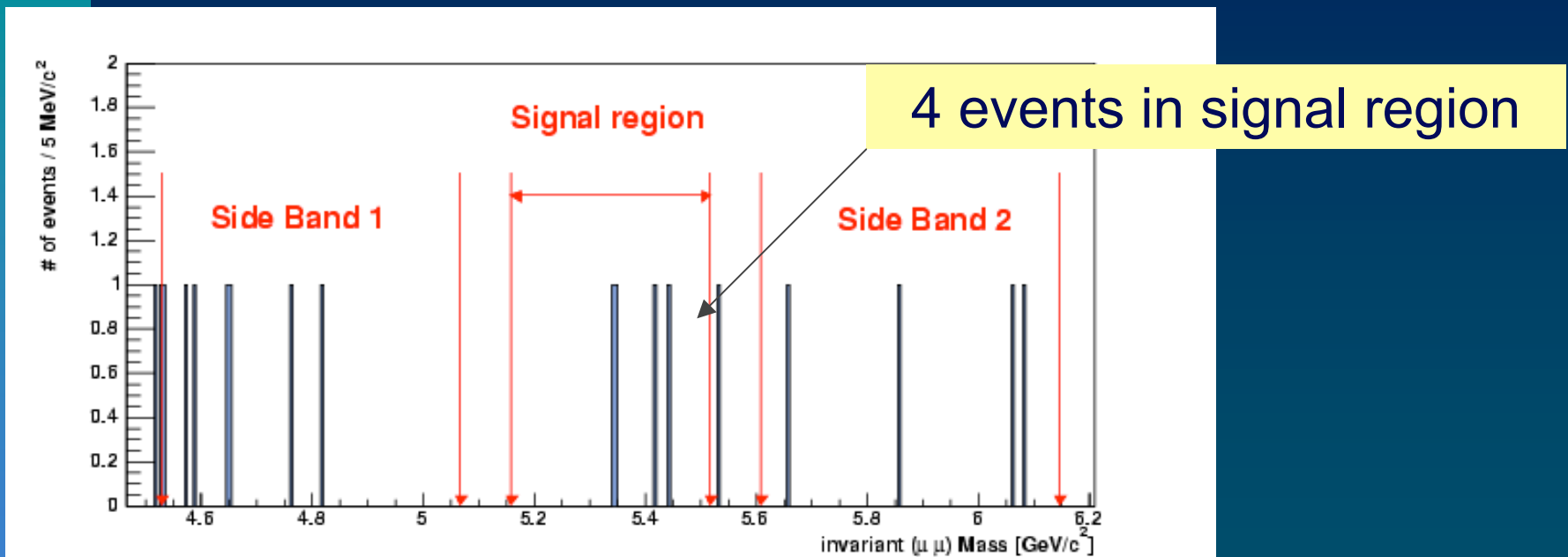
- Random grid search using signal MC and sideband data
 - signal region hidden
- Determined 3 additional cuts:



Opening the box

- Efficiency of additional cuts = $(38.6 \pm 0.7)\%$
- Background prediction = 3.7 ± 1.1 events

240 pb⁻¹

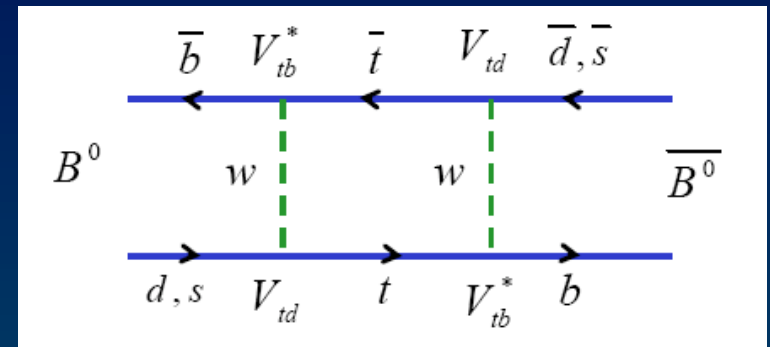
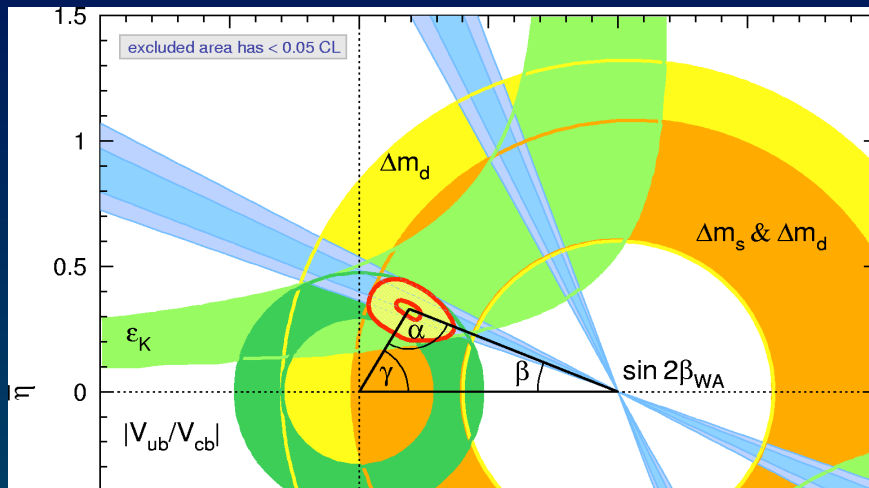


The 95% CL upper limit:

$$BR(B_s \rightarrow \mu^+ \mu^-) < 4.6 \cdot 10^{-7}$$

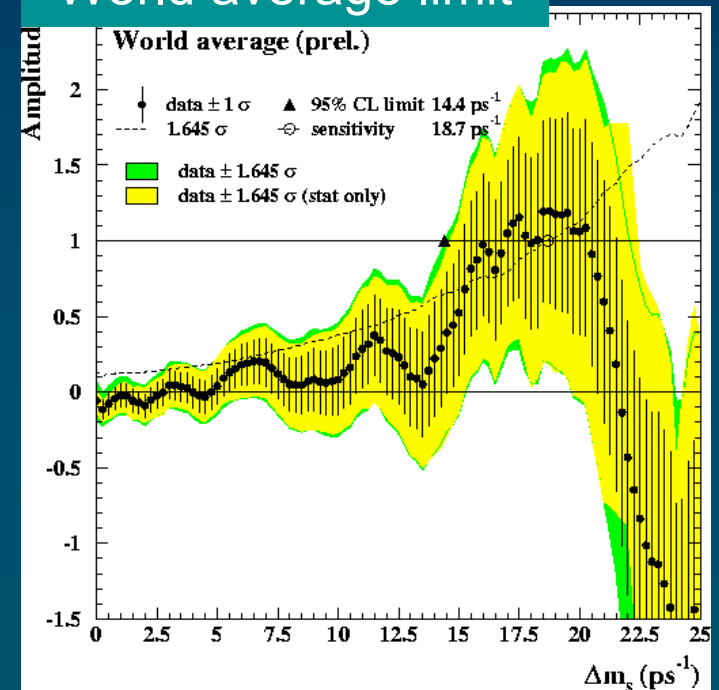
the new best limit - will keep on getting better

B_s mixing



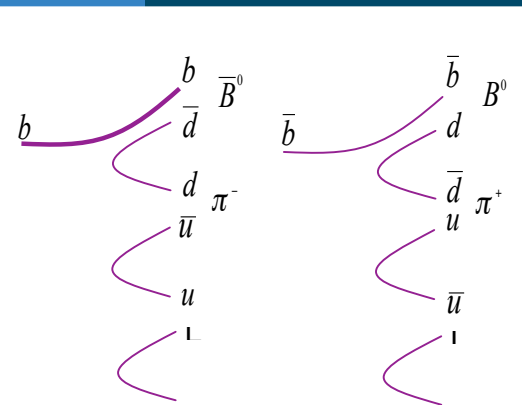
- Measures least known side of unitary triangle
- Can not be done at B factories
- Difficult measurement – requires:
 - High yield, good S/B
 - Oscillations are rapid, so we need excellent lifetime resolution
 - Flavor tagging

World average limit

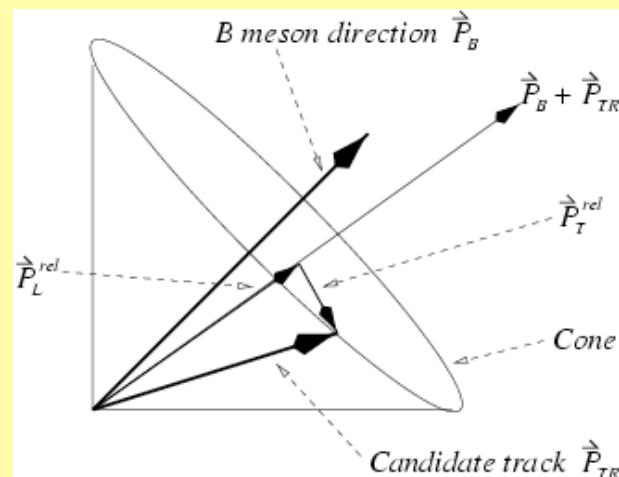


Flavor tagging

Opposite side muon
Q of the highest pT muon in the event separated in ϕ from the signal B by 2.2 rads.

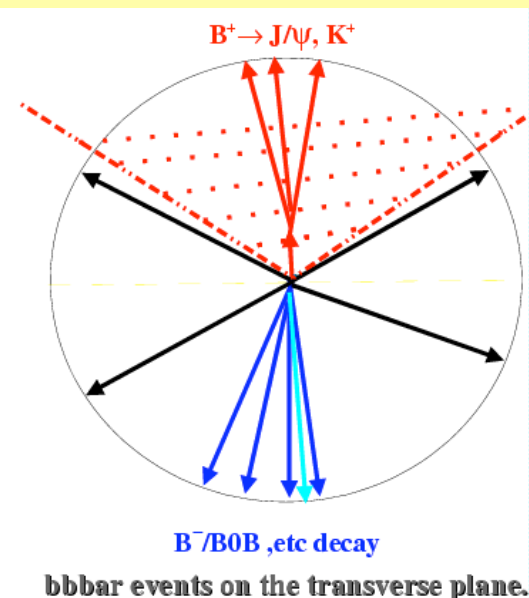


Same side track charge



Q of the highest pT (or lowest pTrel) track in a cone ($dR < 0.7$) around the B

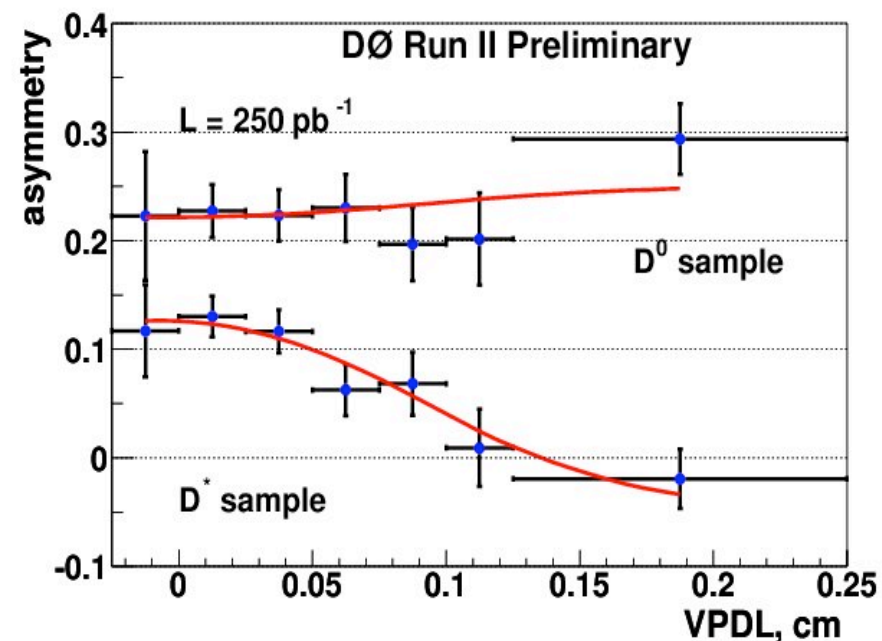
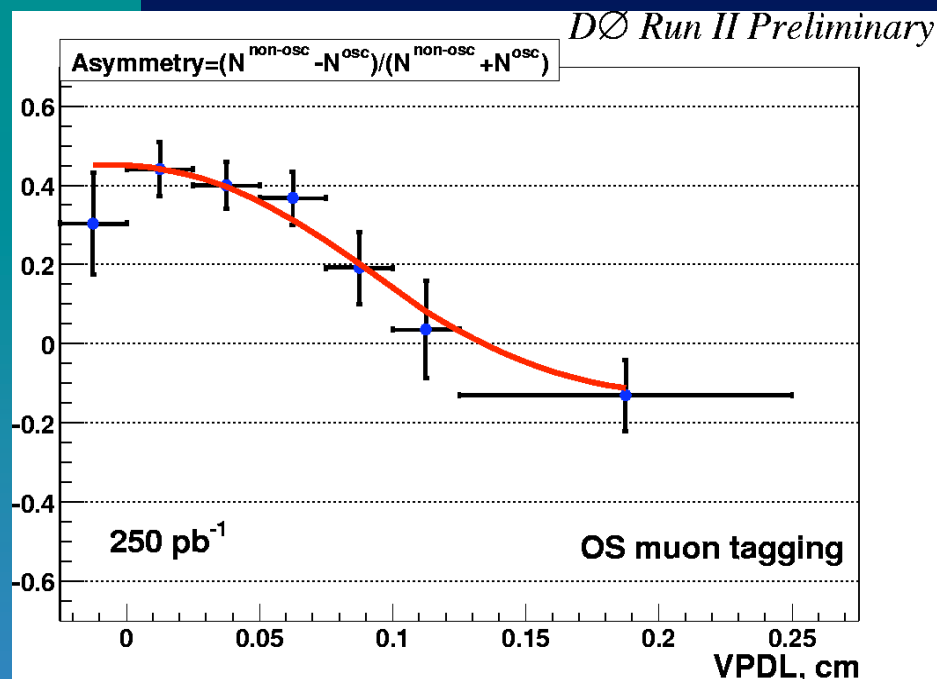
Opposite jet charge



$$\text{Jet } Q = \frac{\sum p_T^i \cdot q^i}{\sum p_T^i}$$

Require $|Q| > 0.2$

B_d mixing first



opposite side muon tag

- Efficiency: $\varepsilon = (4.8 \pm 0.2)\%$
- Dillution: $D = 0.46 \pm 0.04$
- Tag power: $\varepsilon D^2 = (1.0 \pm 0.2)\%$

$$\Delta m_d = 0.506 \pm 0.055 \pm 0.049 \text{ ps}^{-1}$$

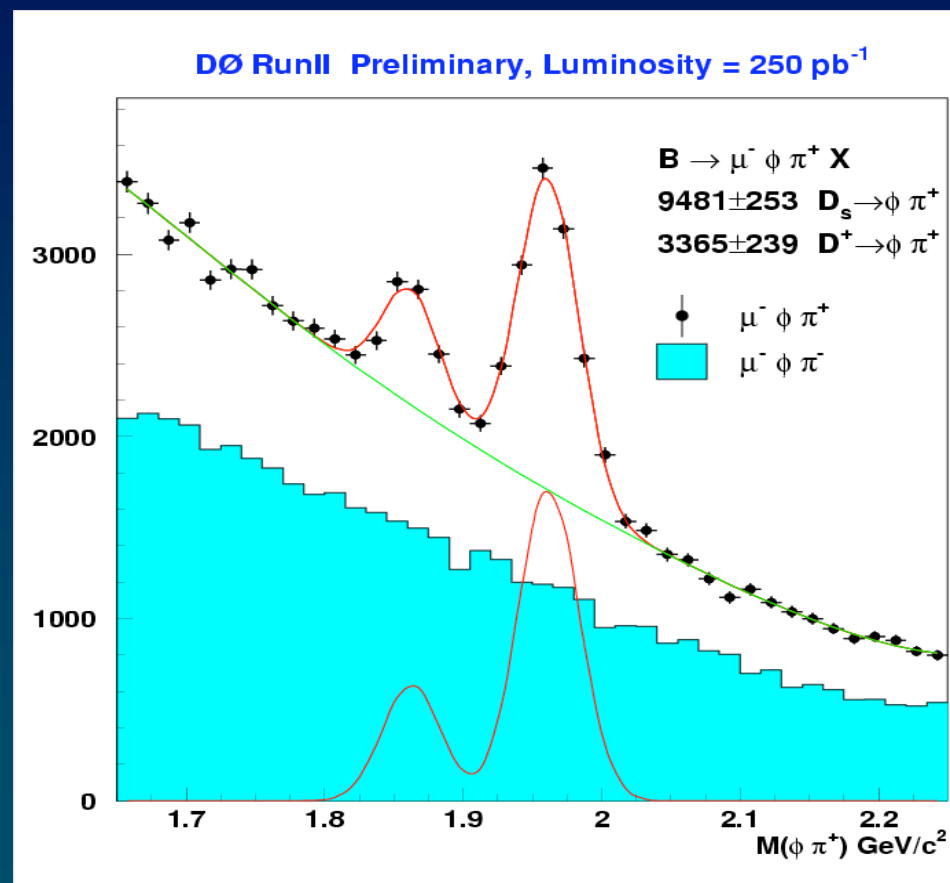
same side track tag

- Efficiency: $\varepsilon = (75 \pm 1)\%$
- Dillution: $D = 0.12 \pm 0.02$
- Tag power: $\varepsilon D^2 = (1.0 \pm 0.4)\%$

$$\Delta m_d = 0.488 \pm 0.066 \pm 0.044 \text{ ps}^{-1}$$

B_s mixing - semileptonic decays

- Easy trigger on lepton in signal – good statistics
 - 38 events/ pb^{-1}
- Degraded proper time resolution due to missing neutrino
 - $\sigma(\tau) \sim 100 - 150 \text{ fs}$
- Tagging Power
 - $\sim D^2 \sim 3 - 10\%$



We are about to turn the crank on a Δm_s measurement using this data

B_s mixing - hadronic decays

■ Difficult trigger, small BR's

- trigger on single muon from other B in event
- $\sim 10\times$ less events, but we are starting to see B_d all hadronic signals
- single muon triggers now saturate extra rate to tape at low luminosities
- specialized B_s triggers now running unprescaled online at all luminosities
- DAQ upgrade proposed to write even more inclusive muon data to tape

■ Excellent proper time resolution

- $\sigma(\tau) \sim 75 - 110$ fs
- will improve with added inner silicon layer in 2005

■ Tagging Power

- $D^2 \sim 60 - 80$ %, self tagging trigger

Conclusions

- DØ has many new beautiful B physics results:
 - Upsilon differential x-sections in pT and rapidity
 - B** mass states separated
 - very precise measurement of $\tau(B^+)/\tau(B^0)$
 - Λ_b lifetime measured in exclusive decay
 - B_s lifetime measured, $\Delta\Gamma_s$ measurement in progress
 - B_c observed, lifetime and mass measured – exclusive mode soon
 - World's best limit on $B_s \rightarrow \mu^+ \mu^-$
 - B_d mixing measured, flavor tags developed
- More data on tape, and many more analyses in progress
- B_s mixing limit (measurement) using semileptonics in the next couple of months
- Longer term, many CKM measurements (and other interesting analyses) are planned